A New Method for Combined Hyperventilation and Hypoxia Training in a Tactical Fighter Simulator

Antti M. Leinonen; Nikke O. Varis; Hannu J. Kokki; Tuomo K. Leino

INTRODUCTION: Physiological episodes are an issue in military aviation. Some non-pressure-related in-flight symptoms are proved to be due to hyperventilation rather than hypoxia. The aim of this study was to validate a new training method provoking hyperventilation during normobaric hypoxia (NH) training in an F/A-18 Hornet simulator.

METHODS: In a double-blind setting, 26 fighter pilots from the Finnish Air Force performed 2 setups in a WTSAT simulator in randomized order with full flight gear. Without the pilot's knowledge, 6% O_2 in nitrogen or 6% O_2 + 4% CO_2 in nitrogen was turned on. Ventilation (VE) was measured before, during, and after hypoxia. S_pO_2 and ECG were monitored and symptoms documented. The subjects performed a tactical identification flight until they recognized symptoms of hypoxia. Thereafter, they performed hypoxia emergency procedures with 100% O_2 and returned to the base with a GPS malfunction and executed an instrument landing system (ILS) approach with the waterline HUD mode evaluated by the flight instructor on a scale of 1 to 5.

RESULTS: Ventilation increased during normobaric hypoxia (NH) from 12 $L \cdot min^{-1}$ to 19 $L \cdot min^{-1}$ at S_pO_2 75% with 6% O_2, and from 12 $L \cdot min^{-1}$ to 26 $L \cdot min^{-1}$ at S_pO_2 77% with 6% O_2 + 4% CO_2. ILS flight performance was similar 10 min after combined hyperventilation and hypoxia (3.1 with 6% O_2 + 4% CO_2 and 3.2 with 6% O_2). No adverse effects were reported during the 24-h follow-up.

DISCUSSION: Hyperventilation-provoking normobaric hypoxia training is a new and well-tolerated method to meet NATO Standardization Agreement hypoxia training requirements.

KEYWORDS: normobaric, aviation, symptoms of hypoxia, hypocapnia, carbon dioxide.

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Physiological episodes (PEs) have been a problem in military aviation during the last decade. The U.S. Navy has reported 571 separate events.[9] PEs were suspected to be related to a malfunction of the On-Board Oxygen Generation System (OBOGS) or the loss of cabin pressurization due to an Environmental Control System (ECS) malfunction. PEs have been caused by multiplatform phenomena, including, for example, the F/A-18 Hornet, F-35, T-45 Goshawk, E/A-6B, and T-6 military aircraft. The latest reports have indicated that the incidence of PEs is decreasing. This is explained by better maintenance of OBOGS and ECS as well as aircrew personal flight equipment.[10] The U.S. Air Force reported 73 hypoxia-like symptoms, including 4 cases with the F-22A and 7 cases with the F-35A during FY 2019. Comparing FY 2019 to FY 2017, the U.S. Navy reported a 74% reduction of PEs in an F/A-18 Hornet fleet and a 96% reduction in the rate of PEs in a T-45 Goshawk fleet from FY 2017 to FY 2019. There is currently no accepted root cause that explains the underlying mechanism—most likely, the background of PEs is multifactorial.[5] A recent study conducted from the UK Eurofighter fleet concluded that most of the in-flight hypoxia-like symptoms reported were due to hyperventilation rather than hypoxia.[1] This is very interesting because there are

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currently no in-flight emergency procedures for hyperventilation in fighter pilots.

Both glucose and oxygen (O_2) are needed for oxidative metabolism in the brain. When an adenosine triphosphate supply is also used during hypoxia, ion pumps cannot maintain transmembrane electrochemical gradients, and widespread membrane depolarization occurs.[8] Therefore, hypoxia causes cognitive deficits that may include impairment of reaction time, decision-making, and certain types of memory. Reflectory hyperventilation during hypoxia leads to hypocapnia, resulting in vasoconstriction in the brain, which reduces the cerebral blood flow.[11]

Symptoms of hypoxia are very similar to those caused by hypocapnia due to hyperventilation and hypoxia symptoms varying between individuals. When the body detects a lowered level of O_2, the physiological response is to hyperventilate.[14] Westerman et al. reported that during normobaric hypoxia (NH), pilots' ventilation (VE) increased from 7 to 16 $L \cdot min^{-1}$.[20] In another study, they concluded that the respiratory rate was raised from 11 to 17 breaths/min.[21] Uchida et al. reported a 10% increase of VE while subjects inspired hypoxic air and the changes were progressive.[16] End-tidal PCO_2 decreases at 25,000 ft (7620 m) in an altitude chamber due to hyperventilation during hypoxia.[2] Especially during short exposure, an equal ventilation response is observed in NH and an altitude chamber at altitudes simulating 25,000 ft or more.[13] Young aviators reported the following symptoms during NH training: heart rate increase 45%, shortness of breath 41%, cognitive impairment 37%, light-headedness 37%, pressure in head 31%, tingling 24%, and visual disturbance 16%.[12]

Hypoxia training in a tactical fighter simulator is mandatory in the Finnish Air Force (FINAF) to refresh a pilot's ability to detect hypoxia symptoms early.[7] The danger of hypoxia in aviation lies in the variety of symptoms as well as the varying speed and order of hypoxia onset due to individual hypoxia physiological responses. Since PEs have recently been reported as including a lot of hyperventilation-related symptoms, the purpose of this study was to validate a new training method to provoke hyperventilation during NH in a tactical fighter simulator. Therefore, we compared our operational hypoxia training gas (6% O_2 in nitrogen) to a new method [6% O_2 + 4% carbon dioxide (CO_2) in nitrogen] during regular training in an F/A-18 Hornet simulator in a tactical flight sortie. Our study hypothesis was that 4% CO_2 and 6% O_2 in nitrogen would enhance hypoxia training and the primary outcome measure was the recognition time of hypoxia symptoms during the two different gas mixture exposures. Secondary outcome measures were VE, subjective symptoms during the exposure, and instrument landing system (ILS) performance 10 min after exposure.

METHODS

Subjects

This is a retrospective analysis of prospectively collected data from mandatory hypoxia training of Hornet pilots in the FINAF in February 2021. The hypoxia training was performed in Fighter Squadron 11 (Rovaniemi, Finland). Although mandatory, each participant gave their informed consent voluntarily and took part in training during working hours between 08:00 and 17:00. Data were available for a total of 26 pilots.

All subjects were healthy male military pilots not on medication, on active flight status in the FINAF, and had passed an aeromedical evaluation in the aeromedical center, Helsinki, Finland, within the previous 12 mo. The median age of the study group was 31 (25–44) yr, and the mean total flight experience was 1070 military flight hours, including 528 flight hours in an F/A-18 Hornet. All of the subjects had a hypoxia refreshment briefing before the training. During the briefing, normal breathing frequency and normal breathing depth were emphasized. The flight surgeon also had an individual briefing before the hypoxia refreshment training, where individual hypoxia symptoms, as well as training documentation, were iterated. Most of the subjects (24 out of 26) had also participated earlier in hypobaric chamber training. Pilots had also had a median of two NH training sessions before this study. The median time of the last fighter simulator NH training was 4.3 yr ago (95% CI 3.4–5.2).

The retrospective analysis of anonymized data was approved by the Committee on Research Ethics of the University of Eastern Finland, Joensuu, Finland (no. 24/2018). The study had the institutional approval of the Defense Command Finland.

Equipment

A fixed-based tactical F/A-18C Hornet Weapons Tactics and Situational Awareness Training Systems simulator (Boeing Corporation, Chicago, IL, USA) was used with a field of view of 180°, including 100% instrumentation compared to a real cockpit. The pilots' flight gear consisted of a Joint Helmet Mounted Cueing System helmet (Collins Aerospace, Charlotte, NC, USA) with a mask (Gentex Corporation, Zeeland, MI, USA) and flight vest with a regulator as normally worn while flying a fighter aircraft.

We commissioned four gas mixtures with different concentrations of O_2 and one also containing CO_2: 100% O_2 (emergency O_2), 21% O_2 (equal to sea level), 6% O_2 in nitrogen, and 6% O_2 + 4% CO_2 in nitrogen. In a study protocol, two different hypoxemic gas mixtures were used to provide differences in VE. Maximum exposure time was 3 min with both hypoxic gases due to training standards set for 6% O_2 by air force command Finland. In our earlier study, 6% O_2 was shown to be the most effective hypoxia training gas since 85% of pilots recognized their hypoxia symptoms faster with this gas mixture.[7] All the gas mixtures were transported to the simulator via a gas selection box (Hypcom, Tampere, Finland) and the flight surgeon was allowed to manually change the gas selection.

Peripheral capillary oxygen saturation (S_po_2) was measured from the forehead (Nonin Medical Inc., Plymouth, MN, USA). Wireless electrocardiograms (ECGs) and VE were also measured (Hypcom, Tampere, Finland), and they were monitored by the flight surgeon to assure the safety of the training. S_po_2, VE, and subjective symptoms were manually saved to a data sheet by an experienced flight nurse. Minute VE was measured from 30-s periods at three points: 1) "beginning" = pilots were climbing toward the target aircraft (Bogie) at low altitude; 2) "exposure" = 45 s after changing to hypoxic gas; and 3) "return" = 120 s after the hypoxia emergency procedures and emergency descent during the return to base (RTB).

In randomized order, 6% O_2 or 6% O_2 + 4% CO_2 cylinders were used in different set-ups to induce hypoxia under normobaric simulator conditions [simulator elevation: 643 ft (196 m)]. Both hypoxic mixtures were prepared to simulate a partial pressure of O_2 at 25,919 ft (7900 m):

6% O_2, 4% CO_2, and 90% N_2 at 760 mmHg;
6% O_2 and 94% N_2 at 760 mmHg.

Before breathing the hypoxic gas mixtures, the subjects used the flight mask to breathe 21% O_2 in 78% N_2 at 760 mmHg.

The ILS approach was evaluated by an experienced flight instructor from simulator data recordings. The ILS flight performance evaluation was done according to the standardized FINAF grading system for flight performance found in the FINAF F/A-18 Standard Operations Manual. The maximum ILS performance score is 5, and the minimum is 1.

Procedure

The training sessions were performed on a double-blinded and randomized basis in the Hornet simulator as part of normal hypoxia training in the Finnish Air Force. Subjects were briefed to breathe as normally as possible to avoid hyperventilation, especially immediately after emergency O_2 introduction. In the tactical Hornet simulator, weather conditions were a runway visual range of 305 ft (1000 m), overcast at 300 ft (91 m), a crosswind of 4 kn, and a cloud top at 13,000 ft (3962 m). After takeoff from Rovaniemi Air Base (EFRO), pilots climbed to 26,000 ft (7925 m) and performed a tactical identification flight led by the fighter controller (GCI). During the operative phase at high altitude, subjects were also given a mental workload by the fighter controller (e.g., altitude restrictions).

The experimental set-up description is presented in **Fig. 1**. At the beginning of both set-ups, the subjects were given pressurized air, but the flight surgeon switched to 6% O_2 or 6% O_2 + 4% CO_2 after randomization during the tactical identification phase. Both subjects and the flight instructor were blinded to the gas mixture used during the set-up. Subjects continued the flight mission until they recognized hypoxia symptoms (no Master Caution or OBOGS DEGD light) and then executed hypoxia emergency procedures. The emergency procedures in hypoxia were: 1) emergency O_2 (100%) on; 2) oxy flow knob off; 3) emergency descent at 20° nose-down attitude below a cabin altitude of 10,000 ft (3048 m); and 4) transponder code 7700 (emergency squawk).

After the hypoxia emergency procedures, pilots returned to the Rovaniemi airfield in instrument meteorological conditions and used the GPS navigation approach technique. The return to base was made more difficult with an inertial navigation system attitude (INS ATT) malfunction, and the pilots had to use the waterline head-up display mode during the ILS 21 approach. The ILS approach was evaluated with the instrument flight examination protocol from the final approach fix to the decision altitude, as published earlier.[19] The mean flight time was 42 min (range 32–50). There was a 15–20-min wash-out period between the two hypoxic gas exposures (RTB and ILS + freeze + flying toward the target aircraft) based on the Air Force Command Finland training limitations. Resuscitation drugs and equipment are mandatory in the simulator during NH training.

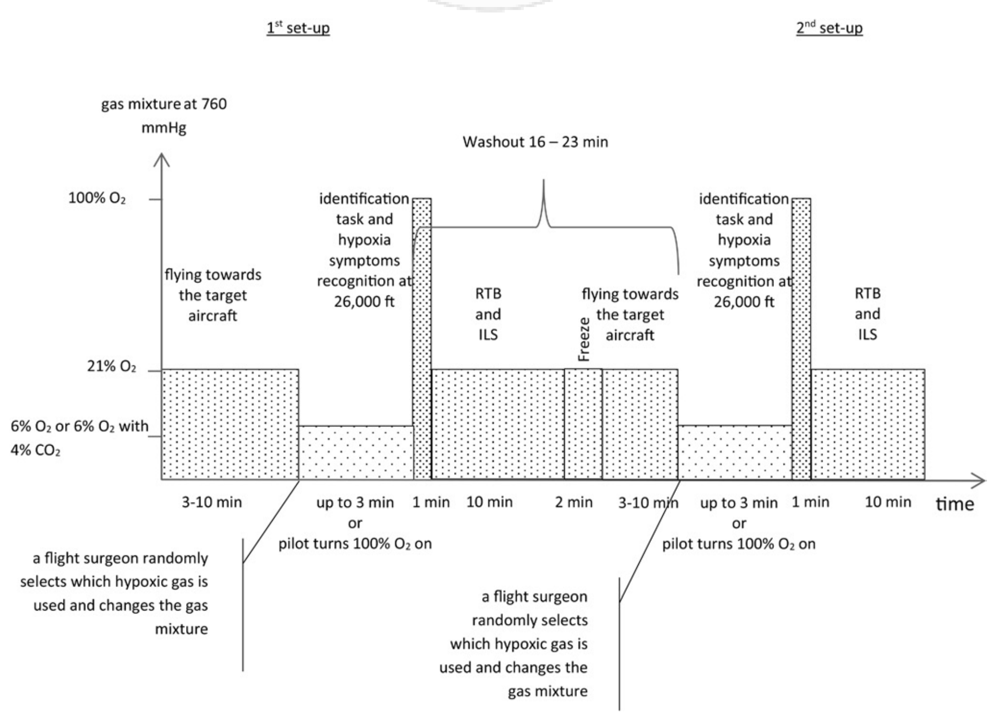

Fig. 1. Experimental set-up description. RTB: return to base; ILS: instrument landing system.

Statistical Analysis

Statistical analyses were performed using SPSS software (IBM SPSS Statistics version 27, International Business Machines Corporation, Armonk, NY, USA). The linear mixed effect (LME) model was used in all comparisons. In the LME models, time was treated as a categorical variable. The models included group, time, and baseline scores as fixed covariates, as well as the group × time interactions. To compare correlations between ventilation during hypoxia exposure and ILS flight performance 10 min after exposure, we calculated the Spearman's correlation coefficient. The data are presented as median and 95% confidence intervals (95% CI). P-values ≤ 0.05 were considered statistically significant.

RESULTS

The median hypoxia-like symptoms recognition time and hypoxia emergency procedures (EP) completion time of two different gas mixtures in the two groups are listed in **Table I**. There was no difference between the two groups, neither at the two time points (P = 0.277) nor taking into account the order of the exposures (P = 0.147). For all 26 subjects, the median recognition time with 6% O_2 + 4% CO_2 gas mixture was 55 s (95% CI 30–97), and with 6% O_2, it was 64 s (95% CI 43–81). Mean ventilation increased during 6% O_2 from 12 L · min^{-1} to 19 L · min^{-1}, and from 12 L · min^{-1} to 26 L · min^{-1} with 6% O_2 + 4% CO_2. The difference was statistically significant.

The order of the exposures had a significant impact on the exposure duration (P = 0.029), but between the two times points, there was no difference (P = 0.051). In the 6% O_2 first group, the median of EP completion time increased from 64 s to 74 s, and in the 6% O_2 + 4% CO_2 first group, it decreased from 67 s to 58 s.

Minute VE, S_pO_2, and heart rate values in the two groups are listed in **Table II**. Hypoxia induced a significant increase in VE with both gas mixtures. The order of the exposures had a significant impact (P < 0.001) on VE during the hypoxia exposure, but between the two times points, there was no difference (P = 0.10). In the 6% O_2 first group, the median of VE increased from 14 L · min^{-1} to 21 L · min^{-1} during the first 6% O_2 exposure compared to the 6% O_2 + 4% CO_2 first group with VE increase from 12 L · min^{-1} to 18 L · min^{-1} during 6% O_2 exposure.

Heart rate increased more in the second exposure (P = 0.002), but the order of the exposures did not contribute (P = 0.091). For all 26 subjects, the median heart rate in the first session before the hypoxia exposure was 84 bpm (95% CI 62–101), and during hypoxia, it was 97 bpm (95% CI 83–139). In the second session, the median heart rate was 80 bpm (95% CI 67–101) before the hypoxia exposure and 95 bpm (95% CI 77–124) during hypoxia.

The mean of the ILS score increased in both groups after the second session compared to the first session (P = 0.004) (**Fig. 2**). There was no difference between the groups. At 10 min after hypoxia emergency procedures, it was 3.1 points

Table I. Median (95% CI) Time for Hypoxia-Like Symptoms Recognition and Time for Hypoxia Emergency Procedures Completion During the Two Gas Exposures.

6% O_2 FIRST GROUP (*N* = 10)	**FIRST EXPOSURE: 6% O_2**	**SECOND EXPOSURE: 6% O_2 + 4% CO_2**
• Recognition time (s)	59 (54, 77)	51 (34, 69)
• EP completion (s)	69 (57, 106)	58 (42, 84)
6% O_2 + 4% CO_2 FIRST GROUP (*N* = 16)	**FIRST EXPOSURE: 6% O_2 + 4% CO_2**	**SECOND EXPOSURE: 6% O_2**
• Recognition time (s)	58 (33, 86)	68 (43, 79)
• EP completion (s)	67 (33, 89)	74 (43, 83)
***P*-VALUES IN MIXED MODEL ANALYSIS**	**RECOGNITION TIME**	**EP COMPLETION**
• Two time points of the exposures	0.277	0.051
• Order of the exposures	0.147	0.029

EP: emergency procedures.

Table II. Median (95% CI) Values for Ventilation, Peripheral Capillary Oxygen Saturation (S_pO_2), and Heart Rate in the Two Groups and Two Exposures.

	6% O_2 FIRST GROUP (*N* = 10)					
	FIRST EXPOSURE, 6% O_2			**SECOND EXPOSURE, 6% O_2 + 4% CO_2**		
	BEFORE	**DURING**	**AFTER**	**BEFORE**	**DURING**	**AFTER**
Ventilation (L · min^{-1})	14 (11, 16)	21 (17, 27)	13 (9, 14)	11 (9, 14)	26 (23, 28)	11 (7, 13)
S_pO_2 (%)	99 (97, 99)	79 (77, 86)	–	98 (96, 99)	82 (75, 88)	–
Heart rate (bpm)	84 (76, 98)	114 (88, 125)	–	83 (77, 92)	95 (84, 109)	–
	6% O_2 + 4% CO_2 FIRST GROUP (*N* = 16)					
	FIRST EXPOSURE, 6% O_2 + 4% CO_2			**SECOND EXPOSURE, 6% O_2**		
	BEFORE	**DURING**	**AFTER**	**BEFORE**	**DURING**	**AFTER**
Ventilation (L · min^{-1})	13 (11, 17)	25 (21, 30)	14 (10, 18)	12 (9, 14)	18 (13, 20)	11 (9, 15)
S_pO_2 (%)	98 (96, 99)	75 (71, 85)	–	98 (95, 98)	73 (70, 85)	–
Heart rate (bpm)	87 (68, 101)	93 (83, 111)	–	79 (70, 90)	101 (83, 122)	–

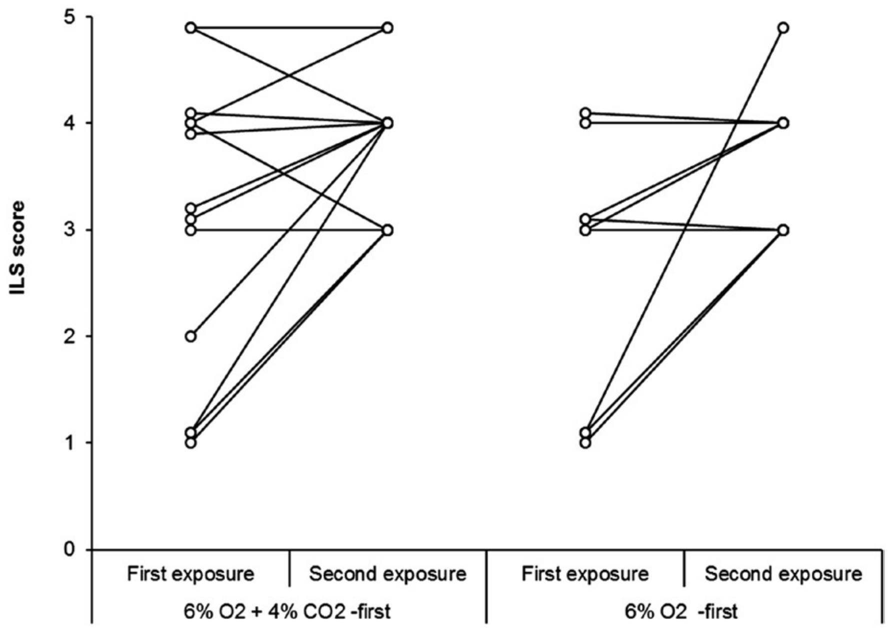

Fig. 2. Evaluation of ILS scores (1–5) at 10 min after the hypoxia exposures. A higher number means better performance. Lines between dots are drawn to demonstrate the performance of the same pilot after the two exposures.

with $6\%\ O_2 + 4\%\ CO_2$ and 3.2 points with $6\%\ O_2$. Ventilation during $6\%\ O_2 + 4\%\ CO_2$ (Spearman's rho 0.039) or $6\%\ O_2$ (Spearman's rho 0.04) exposure was not correlated, with a poor ILS score after 10 min (**Fig. 3**).

The subjective symptoms reported by the subjects after the gas exposures are listed in **Table III**. All pilots reported hypoxia-like symptoms. Subjective symptoms were similar in both groups and both exposures. The most common symptoms reported were difficulty in breathing ($N = 32$), cognitive impairment ($N = 21$), visual impairment ($N = 16$), and a warm sensation ($N = 15$).

There were two subjects who executed hypoxia emergency procedures before hypoxic gas administration. With both subjects, the set-up was restarted. In the second attempt, the recognition times, 53 and 62 s, and the EP completion times, 62 and 66 s, were similar to other subjects. None of the subjects ($N = 26$) reported any adverse effects during the first 24 h after the hypoxia training.

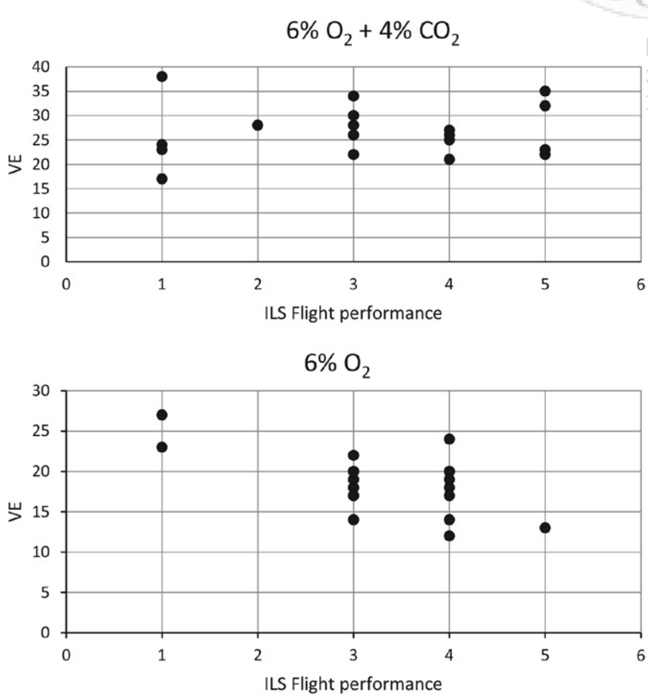

Fig. 3. Ventilation during hypoxia and ILS flight performance 10 min afterwards ($N = 22$).

DISCUSSION

Hyperventilation has been identified as the most common root cause of PEs in military aviation.[1] Therefore, it is vital to find training methods to tackle this problem. Currently, there are no hyperventilation emergency procedures for military fighter pilots. In our study, a new normobaric training gas including $6\%\ O_2$ and $4\%\ CO_2$ in nitrogen resulted in a significantly increased ventilation rate during hypoxia compared to our validated training gas of $6\%\ O_2$. However, the new training also included breathing instructions and subjects were consciously able to reduce their ventilation rate 120 s after hypoxia emergency procedures. Hypoxia symptom recognition time tends to be faster with $6\%\ O_2$ than with $6\%\ O_2 + 4\%\ CO_2$, but the difference was not statistically significant. The order of the exposures had an impact on VE during hypoxic exposure. This first-time effect on ventilation is likely due to arousal from training. In the future, it can be minimized by using $6\%\ O_2 + 4\%\ CO_2$ during the first set-up of hypoxia training.

A large variation in ventilation rate between individuals was also observed in this study. This can be one explanation as to why hypoxia-like symptoms in the same individuals can vary

Table III. Subjective Symptoms Reported by the Subjects.

6% O_2 FIRST GROUP (*N* = 10)		
SYMPTOMS	**FIRST EXPOSURE: 6% O_2**	**SECOND EXPOSURE: 6% O_2 + 4% CO_2**
Total number of reported symptoms	31	27
Difficulty in breathing	5	7
Cognition impairment	5	3
Visual impairment	3	4
Tingling in skin	1	–
Anxiety	1	1
Warm sensation	5	1
Light-headedness	4	2
Feeling of pressure	3	2
Dizziness	2	3
Palpitation	1	1
Air hunger	–	1
Odd taste of metal	1	1
Odd smell	–	1
6% O_2 + 4% CO_2 FIRST GROUP *N* = 16		
SYMPTOMS	**FIRST EXPOSURE: 6% O_2 + 4% CO_2**	**SECOND EXPOSURE: 6% O_2**
Total number of reported symptoms	50	42
Difficulty in breathing	11	9
Cognition impairment	8	5
Visual impairment	4	5
Tingling in skin	4	3
Anxiety	2	3
Warm sensation	5	4
Light-headedness	5	4
Feeling of pressure	2	2
Dizziness	6	5
Palpitation	2	1
Air hunger	1	1

from one hypoxia training to another or a slow ventilator does not identify even a single hypoxia-like symptom. Of student aviators, 42% were not able to recognize any hypoxia symptoms during their very first simulator hypoxia training.[12]

Fifth-generation fighters (e.g., the F-35) have persistent problems with their breathing system.[15] The Pentagon has reported 55 episodes of hypoxia-like symptoms in the F-35 fleet. Therefore, F-35 users have changed their NH training to be repeated annually.[4]

In these training sessions, after both set-ups, the subjects were asked about their symptoms during different gas exposures. With the new 6% O_2 + 4% CO_2 training gas, the difficulty in breathing (shortness of breath) increased from 31 to 46%. On the other hand, the incidence of cognitive impairment only increased from 35 to 42%. Other symptoms included visual impairment, a warm sensation, tingling skin, light-headedness, air hunger, a feeling of pressure, anxiety, and dizziness. Hypocapnea due to hyperventilation may have an effect on hypoxia-like symptoms.

A safe and controlled tactical simulator environment should be used to refresh recognition of hypoxia-like symptoms. Simplicity is important. Our NH training system is transportable and can be attached to a tactical simulator in 30 min. Debriefing is also a very important part of our new training method. A hypoxia instructor should spend at least 20 min with a trained pilot to refresh recognition of symptoms induced by both hypoxia and hyperventilation and deepen the learning of emergency procedures.[3] This helps create a safety margin in the onset of severe cognitive impairment from hypoxia. The simulator flight should be saved on a memory unit to demonstrate decreased flight performance caused by a hypoxia hangover. An exact replication of hypoxia-like symptoms demonstrated in previous NH training is unnecessary since, in the real world, a very large spectrum of hypoxia-like symptoms may indicate a hypoxic environment.

The rise in ventilation may lead to the loss of CO_2 in the body. Hyperventilation-induced hypocapnia can cause respiratory alkalosis. Due to this phenomenon, cerebrovascular vasoconstriction may worsen cognitive performance even more.[6,17] However, use of 4% CO_2 in breathing gas prevents body CO_2 loss and protects from hypocapnia, although ventilation is increased. Thus 6% O_2 + 4% CO_2 gas is likely an even more safe training method than 6% O_2, which the Finnish Air Force has used in hypoxia training since 2008 without any long-term problems. In this NH training, a new training gas was active for less than 90 s. Thus, it is unlikely that the observed hyperventilation would have substantial importance for training safety since ILS flight performance was similar with both training gases being used. It is known that 6% O_2 will result in a 27% decrement in ILS flight performance 10 min after hypoxia emergency procedures,[18] and our ILS flight performance results are in line with the previous study.

The new training gas did not provoke long-lasting symptoms. None of the 26 pilots reported any adverse effects 24 h following hypoxia training with 6% O_2 + 4% CO_2 in nitrogen. This may be because the previous three hypoxia set-ups were used in a single simulator training session.[19] With two hypoxia set-ups, a cumulative effect of hypoxia exposures can be avoided, leading to a well-tolerated training method with the possibility to also train hyperventilation countermeasures after an emergency oxygen activation. NATOPS emergency procedures should include the note “Breath normally during hypoxia emergency procedures and avoid hyperventilating.”

False positives, i.e., pilots executing hypoxia emergency procedures without the introduction of a hypoxic gas mixture, were also seen in two of the pilots. In these cases, it is important to freeze the set-up go-through situation and repeat the set-up from the beginning. The recognized symptoms of these pilots were due to hyperventilation caused by the cognitive workload of the identification flight mission. We propose that more individual, customized hypoxia training will be the future of hypoxia training instead of the rigid 3 to 5 yr interval between hypoxia training sessions.

In conclusion, a new method of combined hyperventilation and NH training was validated in a tactical Hornet simulator. Hyperventilation training can also be provided with 6% O_2 with 4% CO_2 gas after the introduction of 100% emergency O_2 when air hunger is at the maximum. No adverse effects were reported and 6% O_2 + 4% CO_2 in nitrogen prevents body CO_2

loss and risk of hypocapnia. More research is needed to understand the complicated relationship between hyperventilation, hypocapnia, hypoxia, and flight performance.

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